



UNIVERSITI PUTRA MALAYSIA

**APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN
QUANTITATIVE ASSESSMENT OF GROUNDWATER
RESERVE OF UNCONFINED AQUIFER**

HAGO ALI HAGO

FSAS 2000 12

**APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN
QUANTITATIVE ASSESSMENT OF GROUNDWATER
RESERVE OF UNCONFINED AQUIFER**

BY

HAGO ALI HAGO

**Thesis Submitted in Fulfilment of Requirements for the Degree of Master
of Science in the Faculty of Science and Environmental Studies
Universiti Putra Malaysia**

January 2000



DEDICATED TO

The soul of my beloved brother **Mohammed El Fadi El Amin**
in his falseless abode. Who was my true mentor in the
wisdom of his words and in the strength
of his protection. May Allah
accept him as a true
shahid.

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

**APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN
QUANTITATIVE ASSESSMENT OF GROUNDWATER
RESERVE OF UNCONFINED AQUIFER**

By

HAGO ALI HAGO

January 2000

Chairman: Associate Professor Shaharin Ibrahim, Ph.D.

Faculty: Science and Environmental Studies

The thesis describes the application of the electrical resistivity method in groundwater exploration carried out at Bukit Jalil-Serdang area, Selangor Darul Ehsan, Malaysia. Electrical Resistivity Imaging surveys have been conducted in order to locate, delineate subsurface water resources and estimate its reserve. A Wenner electrode configuration was employed. The field survey was conducted along thirteen profiles providing continuous coverage. Color-modulated sections of resistivity versus depth were plotted for all lines, giving an approximate image of the subsurface structure. The field survey was accompanied by a laboratory work. Resistivity of rock and soil samples taken from the field was measured and the resistivity formation factors were obtained. The porosity of the same sample was

calculated. A relationship between the porosity and the formation factor has been established. The laboratory established relationship was applied to the data obtained in the field to calculate the porosity values of the formation present within the investigated area. The porosity values were contoured and plotted. Depth to the bedrock for each line was obtained. A 2-dimensional and 3-dimensional representation of the subsurface topography of the area was prepared using a commercial computer software. The use of the software also enabled the computation of groundwater reserve within the investigated area.

The results showed that the layer associated with the aquifer has resistivities between 20 Ω .m and 150 Ω .m and is located at a depth varying from 5 to 20m. The layer has porosity between 18% and 35%. The results obtained from the electrical resistivity profiles indicate that the aquifer occupies a surface area of about 15977900 m² and has a mean depth of 13m, with net volume of 204610000 m³. The average aquifer porosity is 30%. Therefore, a usable capacity of about 61,383,000 \pm 6,752,130 m³ can be inferred.

Abstrak tesis ini dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk mendapatkan Ijazah Master Sains.

**PENGUNAAN KAEDAH KERINTANGAN ELEKTRIK DALAM
PENINJAUAN SECARA KUANTITATIF SIMPANAN AIR BAWAH
TANAH UNTUK AKUIFER TERBUKA**

Oleh

HAGO ALI HAGO

Januari 2000

Pengerusi: Profesor Madya Shaharin Ibrahim, Ph.D.

Fakulti: Sains dan Pengajian Alam Sekitar

Kajian ini menerangkan satu contoh penggunaan kaedah kerintangan elektrik dalam eksplorasi air bawah tanah yang telah dijalankan dikawasan Bukit Jalil-Serdang, di Negeri Selangor Darul Ehsan, Malaysia. Tinjauan pengimejan kerintangan elektrik telah dijalankan untuk mengenalpasti lokasi dan memetakan sumber air bawah tanah serta menganggarkan jumlah kandungan air yang terdapat didalam sumber tersebut. Konfigurasi elektrod Wenner telah digunakan dalam kajian ini. Kerja lapangan di sepanjang tiga belas profil telah dikendalikan. Keratan rentas bermodulasikan warna bagi kerintangan bahan melawan kedalaman telah diplot untuk semua profil yang menghasilkan imej bagi struktur dibawah tanah. Kajian dimakmal juga telah dijalankan bersama-sama kajian dilapangan.

Kerintangan sampel batuan dan tanah telah diukur. Jumlah kandungan liang rongga bagi sampel-sampel batuan dan tanah ini juga telah dikira. Daripada nilai kerintangan ini, faktor formasi telah diperolehi. Satu hubungan antara jumlah kandungan liang rongga dan faktor formasi telah diperolehi. Kaitan faktor formasi-kandungan liang rongga ini telah diaplikasikan keatas data-data kerintangan elektrik yang diperolehi dari lapangan. Penggunaan kaitan ini telah menghasilkan nilai keronggaan bagi formasi-formasi batuan dikawasan kajian.

Nilai-nilai jumlah kandungan liang rongga telah dikontur dan diplotkan. Kedalaman batuan dasar di bawah tiap-tiap geris rentasan telah diperolehi. Satu gambaran 2-dimensi dan 3-dimensi topografi permukaan batuan dasar telah disediakan dengan menggunakan perisian komersial. Penggunaan perisian ini juga telah membolehkan pengiraan jumlah kandungan air tanah yang terdapat di kawasan kajian.

Keputusan menunjukkan lapisan pada akuifer memiliki kerintangan di antara 20 Ω .m dan 150 Ω .m dan berada pada kedalaman yang di antara 5 hingga 20 m. Lapisan ini mempunyai jumlah kandungan liang rongga di antara 18% dan 35%. Keputusan daripada profil kerintangan elektrik menunjukkan, akuifer yang dikaji meliputi kawasan permukaan seluas 15,977,900 m² dan memiliki purata

kedalaman 13 m dari permukaan dengan isipadu bersih 204,610,000 m³. Purata jumlah liang rongga bagi akuifer ialah 30%. Oleh itu kapasiti penggunaan 61,383,000 ± 6,752,130m³ boleh diperolehi.

ACKNOWLEDGMENTS

Firstly Praise be to Allah for giving me the strength and patience to complete this work and Peace be upon his final Prophet and Messenger Mohammed. My full thanks to associate professor, Dr. Shaharin bin Ibrahim, chairman of my supervisory committee, for his useful discussions, invaluable suggestions, unlimited assistance, beneficial advice and continuous encouragement through out this work. I have the highest regard for his professional courtesy and the profound humility of his character.

Similar thanks must go to members of my supervisory committee, associate professor Dr. Wan Nor Azmin bin Sulaiman and associate professor, Dr. Mohd Kamil bin Yusoff, for taking interest in and offering helpful suggestions and guidance.

I would like to thank members and staff in the department of physics who have always willing to offer assistance, in particular, Mr. Mohd Shah Ibrahim, Mr. Roslim Mohd, Mr. Nordin Abdul Kadir and Mr. Razak Harun. I would like to take this opportunity to express my thanks to my friends who have helped me in this work: Mr. Ugantharan Maruthaveeran, Mr. Abdelatif Mukhtar, Mr. Elrashied Imam Elkhidir and Mr. Elsadig Eljack.

Higher Education Ministry (Sudan) and Malaysian Technical Corporation program (MTCP) which is highly appreciated and gratefully acknowledged provided financial support. May Allah reward my supervisor and committee for their dedication and service to humankind.

I certify that an Examination Committee met on January 27, 2000, to conduct the final examination of Hago Ali Hago Ali, on his Master of Science thesis entitled "Application of Electrical Resistivity Method in Quantitative Assessment of Groundwater Reserve of Unconfined Aquifer" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

PAUZIAH ABD. LATIF, Ph.D.

Lecturer, Department of Environmental Studies
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Chairman)

SHAHARIN IBRAHIM, Ph.D.

Associate Professor, Physics Department
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

MOHD KAMIL YUSOFF, Ph.D.

Associate Professor, Department of Environmental Studies
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

WAN NOR AZMIN SULAIMAN, Ph.D.


Lecturer, Department of Environmental Studies
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)



MOHD GHAZALI MOHAYIDIN, Ph.D.
Professor /Deputy Dean of Graduate School
Universiti Putra Malaysia

Date: **24 FEB 2000**

This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfillment of the requirements for the degree of Master of Science.


KAMIS AWANG, Ph.D.
Associate Professor
Dean of Graduate School
Universiti Putra Malaysia

Date: 11 MAY 2000

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



Hago Ali Hago Ali

Date: 24 / 2 / 2000

TABLE OF CONTENTS

	Page
DEDICATION.....	ii
ABSTRACT.....	iii
ABSTRAK.....	v
ACKNOWLEDGEMENTS.....	viii
APPROVAL SHEETS.....	x
DECLARATION FORM.....	xii
LIST OF TABLES.....	xvii
LIST OF FIGURES.....	xix
CHAPTER	
I INTRODUCTION.....	
Previous Work in the Study Area.....	3
Objectives of the Present Study.....	3
The Study Area.....	4
Drainage.....	5
Topography.....	6
Climate.....	6
Vegetation.....	7
Layout of the Thesis.....	7
II LITERATURE REVIEW.....	
Introduction.....	9
Role of Geophysics in Groundwater Prospecting and Hydrogeology.....	10
The Use of the Resistivity Method in Groundwater Prospecting.....	16
III GEOLOGY OF THE STUDY AREA.....	
Introduction.....	35
Kenny Hill Formation.....	37
Occurrence.....	37
Lithology.....	38
Structure.....	41
Fossils and Age.....	42
Origin of Sediments.....	44
Tectonic History.....	46
VI METHODS OF INVESTIGATIONS.....	
Introduction.....	48
Traditional Resistivity Surveys.....	49



The Relationship between Geology and Resistivity.....	52
Earth Resistivity Method.....	54
Electrode Configuration used.....	58
Wenner Configuration.....	58
2-D Electrical Imaging Surveys.....	59
Introduction.....	59
Field Survey Method.....	62
Pseudosection Data Plotting Method.....	65
The Advantages and Disadvantages of the Different Arrays.....	67
Wenner Array.....	71
Dipole-Dipole Array.....	72
Schlumberger Array.....	73
Summary.....	74
Interpretation of Resistivity Field Data with the Aid of Computer.....	74
Contouring of Porosity Values.....	76
 V	
LABORATORY DETERMINATIONS OF PETROPHYSICAL PROPERTIES.....	78
Introduction.....	78
Total Porosity and Effective Porosity.....	79
Total or Absolute Porosity.....	79
Effective Porosity.....	80
Rocks and their Porosity.....	80
Determinations of Effective Porosity of the Core Samples.....	81
Introduction.....	81
Methodology.....	82
Selection and Preparation of Samples.....	82
Cleaning of Samples.....	82
Drying of Samples.....	83
Weighing of Samples and Volume Determination	83
Saturation of Samples.....	84
Calculations of Effective Porosity.....	84
Determinations of Hydraulic Conductivity of the Core Samples.....	85
Introduction.....	85
Darcy's Law.....	86
Permeability.....	86
Determinations of Hydraulic Conductivity.....	88
Laboratory Methods.....	88
Equation for the Determination of Hydraulic Conductivity of a Rock Specimen by the Falling Head Method.....	90
Determination of Electrical Resistivity.....	94

	Introduction.....	94
	Methodology.....	95
	Preparation of Core Samples.....	95
	Sample Drying.....	95
	Samples Saturation with Electrolyte Solution.....	96
	Measurements of Resistivity.....	97
	Formation Factor.....	99
	Methods of Calculation.....	99
	Measurements of Parameters on Soil Samples.....	101
	Porosity.....	101
	Hydraulic Conductivity.....	103
VI	RESULTS AND DISCUSSION.....	105
	Introduction.....	105
	Laboratory Work.....	106
	Effective Porosity.....	106
	The Variation of Electrical Resistivity, Formation Factor and Fractional Porosity of Earth Materials from the Study Area.....	107
	Hydraulic Conductivity.....	114
	2 Dimensional Electrical Resistivity Imaging.....	118
	Bukit Jalil Line 1.....	118
	Bukit Jalil Line 2.....	120
	Bukit Jalil Line 3.....	121
	Bukit Jalil Line 4.....	122
	Bukit Jalil Line 7.....	123
	Bukit Jalil Line 5.....	124
	Bukit Jalil Line 6.....	125
	Bukit Jalil Line 8.....	126
	Apm Line	127
	Taman Uninersity Line	128
	Mardi Line 1.....	129
	Mardi Line 2.....	130
	Mardi Line 3.....	131
	Porosity Distribution.....	132
	Porosity Distribution along Electrical Resistivity Imaging Lines.....	135
	Bukit Jalil Line 1.....	135
	Bukit Jalil Line 2.....	136
	Bukit Jalil Line 3.....	137
	Bukit Jalil Line 4.....	138
	Bukit Jalil Line 7.....	139
	Bukit Jalil Line 5.....	140

Bukit Jalil Line 6.....	141
Bukit Jalil Line 8.....	142
Apm Line	143
Taman University Line	144
Mardi Line 1.....	145
Mardi Line 2.....	146
Mardi Line 3.....	147
Bedrock Elevation and the Estimation of Groundwater Reserve.....	148
VII SUMMARY AND CONCLUSION.....	152
BIBLIOGRAPHY.....	154
APPENDICES.....	165
A Borehole Geological Logging.....	166
B Laboratory Investigations.....	169
C Interpretation of Resistivity Field Data with the Aid of Computer.....	174
D Relationship between Porosity and Formation Factor using Curve Fit.....	187
E Determination of the Total Volume of the Aquifer.....	189
BIODATA.....	191

LIST OF TABLES

Table		Page
1	Resistivity of Some Rocks, Minerals, Chemicals and Metals.....	53
2	The Effective Depth of Investigation for the Different Arrays.....	70
3	Average Porosities of Some Rocks.....	81
4	Correlation Between Porosity and Permeability.....	88
5	Representative Values of Hydraulic Conductivity.....	89
6	Electrical Resistivity of Earth Materials.....	107
7	Variation of Formation Factor against Porosity of Rock Samples.....	108
8	Variation of Formation Factor against Porosity of Soil Samples.....	110
9	Variation of Formation Factor against Porosity of Rock and Soil Samples.....	111
10	Variation of Formation Factor against Hydraulic Conductivity of Rock Samples.....	115
11	Variation of Formation Factor against Hydraulic Conductivity of Rock and Soil Samples.....	117
12	Conversion of Electrical Resistivity Values into Porosity.....	133
13	Calculation of Porosity for Rock Samples.....	169
14	Calculation of Porosity for Soil Samples.....	171
15	Calculation of Hydraulic Conductivity for Rock Samples.....	172
16	Calculation of Hydraulic Conductivity for Soil Samples.....	173

17	Elevation of the Bedrock.....	189
18	Depth to the Bedrock.....	190



LIST OF FIGURES

Figure		Page
1	Map Showing the Location of the Study Area, Samples and Electrical Resistivity Imaging Lines.....	2
2	Geology of the Study Area.....	36
3	The Three Different Models Used in the Interpretation of Resistivity Measurements.....	51
4	A Graphical Plot of the Resistivity Values of Different Types of Materials.....	55
5	A Conventional Four-Electrode Array to Measure the Subsurface Resistivity.....	56
6	Electrode Spreads in Common Use.....	61
7	The Arrangements of Electrodes for A 2D Electrical Resistivity and Sequence of Measurements Used to Build Up A pseudosection.....	64
8	The Sensitivity Pattern for the Wenner, Schlumberger and Dipole-Dipole Arrays.....	69
9	Dipix-Plus for Plotting and Contouring of Dipole-Dipole Resistivity Data, IP Data and Profiling Data.....	77
10	Experimental Apparatus for the Illustration of Darcy's Law.....	87
11	Permeameter for Measuring Hydraulic Conductivity of Geologic Samples by Falling Head Method.....	91
12	An Example of the Variation of $\log_{10} h_1$ as A Function of Time.....	93
13	Resistivity Measuring Cell.....	98
14	Permeameter for Measuring Hydraulic Conductivity of Geologic Samples by Constant Head Method.....	104

15	Variation of Formation Factor against Porosity of Rock Samples.....	109
16	Variation of Formation Factor against Porosity of Soil Samples.....	110
17	Variation of Formation Factor against Porosity of Rock and Soil Samples.....	113
18	Variation of Formation Factor against Hydraulic Conductivity of Rock Samples.....	116
19	Variation of Formation Factor against Hydraulic Conductivity of Soil Samples.....	117
20	Distribution of Electrical Resistivity Values along Bukit Jalil Line 1....	119
21	Distribution of Electrical Resistivity Values along Bukit Jalil Line 2....	120
22	Distribution of Electrical Resistivity Values along Bukit Jalil Line 3....	121
23	Distribution of Electrical Resistivity Values along Bukit Jalil Line 4...	122
24	Distribution of Electrical Resistivity Values along Bukit Jalil Line 7....	123
25	Distribution of Electrical Resistivity Values along Bukit Jalil Line 5....	124
26	Distribution of Electrical Resistivity Values along Bukit Jalil Line 6....	125
27	Distribution of Electrical Resistivity Values along Bukit Jalil Line 8....	126
28	Distribution of Electrical Resistivity Values along Apm Line.....	127
29	Distribution f Electrical Resistivity Values along Taman University Line.....	128
30	Distribution of Electrical Resistivity Values along Mardi Line 1.....	129
31	Distribution of Electrical Resistivity Values along Mardi Line 2.....	130
32	Distribution of Electrical Resistivity Values along Mardi Line 3.....	131
33	Subsurface Porosity Distribution along Line Bukit Jalil 1.....	135

34	Subsurface Porosity Distribution along Line Bukit Jalil 2.....	136
35	Subsurface Porosity Distribution along Line Bukit Jalil 3.....	137
36	Subsurface Porosity Distribution along Line Bukit Jalil 4.....	138
37	Subsurface Porosity Distribution along Line Bukit Jalil 7.....	139
38	Subsurface Porosity Distribution along Line Bukit Jalil 5.....	140
39	Subsurface Porosity Distribution along Line Bukit Jalil 6.....	141
40	Subsurface Porosity Distribution along Line Bukit Jalil 8.....	142
41	Subsurface Porosity Distribution along Apm Line.....	143
42	Subsurface Porosity Distribution along Taman University Line.....	144
43	Subsurface Porosity Distribution along Mardi Line 1.....	145
44	Subsurface Porosity Distribution along Mardi Line 2.....	146
45	Subsurface Porosity Distribution along Mardi Line 3.....	147
46	Bedrock Contour.....	150
47	3-D View of the Top of the Bedrock.....	151
48	3-D view of the Depth to the Bedrock.....	151
49	Geological Profile for Borehole 1.....	166
50	Geological Profile for Borehole 2.....	167
51	Geological Profile for Borehole 3.....	168
52	Variation of Formation factor against Porosity of Rock and Soil Samples using Curve Fit.....	188

CHAPTER I

INTRODUCTION

Groundwater is a major source of clean drinking water all over the world. It has been an important resource especially in the dry part of the world. Groundwater has been used in Malaysia for many decades (Ang, 1994).

Increased demands for water have stimulated development of underground water resources. As a result, techniques for investigating the occurrence and movement of groundwater have been improved, better equipment for extracting has been developed, concepts for resource management have been established, and the research has contributed to a better understanding of the subject.

Since geophysical exploration is the scientific measurement of physical properties of the earth crust for investigation of mineral deposits or geologic structure, the present project conducted mainly to apply electrical resistivity method in groundwater exploration, in particular to estimate the groundwater reserve within the unconfined aquifer.

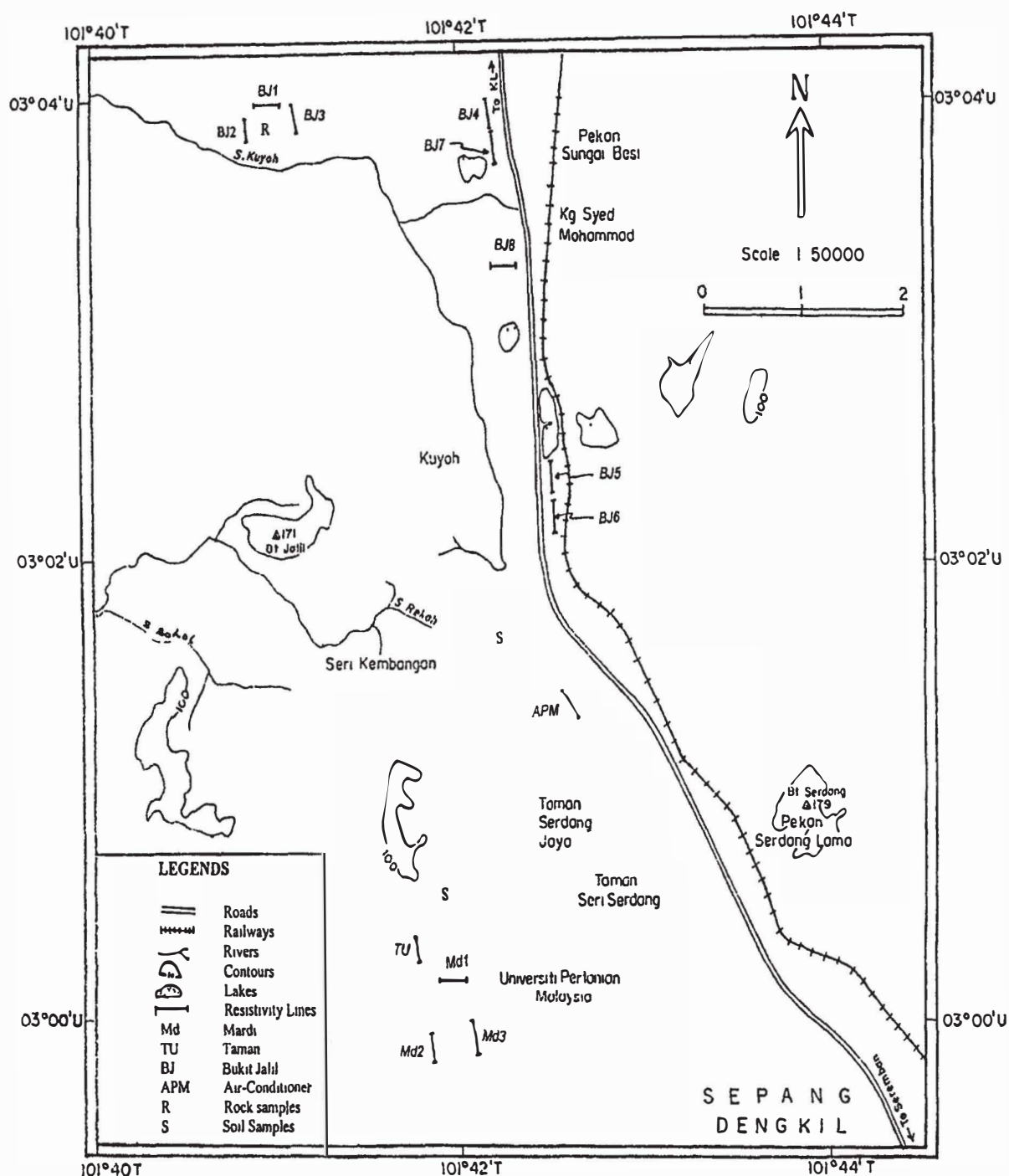


Figure 1: Map Showing the Locations of the Study Area, Samples and Electrical Resistivity Imaging Lines

PREVIOUS WORK IN THE STUDY AREA

The geological survey of Malaysia first started hydrogeological investigations in Peninsular Malaysia in 1903. The only previous published account of the geology of the whole of the present area was entitled "Account of the geology and mining industries of south Selangor and Negeri Sembilan" (Willbourn 1922). A geological map accompanies this publication on a scale of 1 inch to 4 miles.

Ahmed and Othman (1992, 1997), using DC resistivity and other methods to provide sharp lateral resistivity variations by electrical profiling carried out two geophysical investigations. The resistivity profiling was carried out at Sungai Besi Toll plaza along the Kuala Lumpur-Seremban Highway using Wenner array with 10m-electrode spacing. They found that in the first line, the southern part has low resistivity value due to higher water and higher clay content. In the second line the resistivity profiling results show localized anomalies occurring at several parts of the line which is most probably due to the presence of weak zones in the sediment layer.

OBJECTIVES OF THE PRESENT STUDY

The primary objective of the present study is to apply electrical resistivity method in the quantitative assessment of groundwater reserve. From the combination of the resistivity techniques used in the field, processing and